



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets



(11) Publication number:

0 343 580 B1

(2)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: 10.03.93 (51) Int. Cl. 5: G07C 9/00

(21) Application number: 89109221.5

(22) Date of filing: 23.05.89

(54) Method and apparatus for matching fingerprints.

(30) Priority: 24.05.88 JP 127826/88
24.05.88 JP 127827/88

(43) Date of publication of application:
29.11.89 Bulletin 89/48

(45) Publication of the grant of the patent:
10.03.93 Bulletin 93/10

(64) Designated Contracting States:
DE FR GB

(66) References cited:
EP-A- 0 050 842 EP-A- 0 251 504
WO-A-86/06527 WO-A-87/06378
GB-A- 2 050 026 US-A- 4 581 760

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Description

The present invention relates to a method and an apparatus for matching fingerprints.

The principle of the prior art concerning the matching of fingerprints is as follows. A fingerprint is composed of lines known as ridges, which have branching parts (bifurcations) and abrupt endings (end points). These bifurcations and end points are known as minutiae. Two fingerprints will be identified with one another if the positions of and relations among pairs of such points match each other as a rule without excess or deficiency.

For details of a fingerprint matching apparatus based on this principle, reference may be made to the U.S. Patent No. 4,646,352. When a fingerprint is registered with it, this apparatus extracts, and files, the minutiae and inter-minutia relations from the fingerprint to be registered. In collating a newly inputted fingerprint image, its minutiae and inter-minutia relations are extracted, and the extracted minutiae and their relations are compared with those of filed fingerprints to compare whether the new fingerprint can be identified with one of the filed fingerprints.

This apparatus, however, requires a vast quantity of calculations to extract minutiae and their relations from each fingerprint image.

Therefore, this apparatus proves highly useful in criminal investigations using a large general-purpose computer or a supercomputer in which a suspect is to be identified by the fingerprints left by the offender.

However, where the fingerprint of the individual to be identified is already known, such as in entrance control, and a fingerprint presented for entrance clearance by that particular individual is to be collated with his or her registered fingerprint, quick processing is required with a low-cost processing apparatus inferior in computing capacity.

For a technology meeting this requirement, reference may be made to Koichiro Morita and Ko Asai, "Automatic fingerprint identification terminal for personal verification" in PROCEEDINGS OF SPIE - The International Society for Optical Engineering, Society of Photo-Optical Instrumentation Engineers, 1986, pp. 174-181. The terminal described in this literature, at the time of registration when no particularly quick processing is demanded, executes the processing to extract minutiae and their relations to prepare and file a list of the minutiae of the fingerprint to be registered. On the other hand, at the time of collation when high-speed processing is needed, information on the minutiae in the filed list is referred to, the presence or absence of the minutiae referred to in the inputted fingerprint image is checked and, if they are found present, the number of ridges is counted as

representing the relations among the minutiae. Then the inputted fingerprint is collated according to the presence or absence of the minutiae and the number of ridges to identify it, or deny its identity, with the registered fingerprint.

Thus collation by a processing apparatus inferior in computing capacity uses a method to check whether the minutiae stated in the list of registered minutiae are present and, if they are, whether the number of ridges in every pair of such minutiae is equal to what is registered.

Therefore, this method has a first disadvantage of recognizing identity and processing accordingly if the minutiae registered in the list of minutiae are present and the number of ridges between every pair of minutiae is equal to what is registered even though the inputted fingerprint has such minutiae as should not be in the registered one. In other words, this is the disadvantage of a high possibility of inviting wrong recognition because of the absence of information for collation in the area where no minutiae are present.

There is another disadvantage, which concerns security. It is supposed here that a mechanism which requires the execution of collation and the result thereof has no capabilities to detect the aforementioned minutiae and to count the number of ridges between them while there is an apparatus having such capabilities outside the mechanism, and the leak of the contents of the list of minutiae out of said mechanism should be prevented.

A first specific example of this situation may be a case in which a person desiring access to an IC card is to be identified by his or her fingerprint.

Usually, an integrated circuit built into an IC card has no video processing capability on account of various constraints. Moreover, an available external apparatus is likely to be too small a terminal unit to be able to quickly prepare a list of minutiae from an inputted fingerprint image.

There is the disadvantage that, in this situation, providing the list of minutiae registered in the IC card to the external apparatus would make it impossible for the function of "identification" to be performed.

A second specific example is a system in which a center for concentrated management of the lists of registered minutiae and terminal units installed where entrance control is performed are linked by communication lines.

Any of the terminal units in this system would not be capable of quickly preparing a list of minutiae from an inputted fingerprint image. There further might be the disadvantage that it is not always possible to send the inputted fingerprint image to the center because of the limitation of the line capacity.

A main object of the present invention is to provide a method and an apparatus for the matching of fingerprints cleared of the foregoing disadvantages and improved in collation rate.

Another object of the invention is to provide a method and an apparatus for the matching of fingerprints cleared of the foregoing disadvantages and improved in the security aspect.

These objects are solved with the features of the claims.

Features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates a first preferred embodiment of the invention;

FIG. 2 shows personal fingerprint data prepared by the first preferred embodiment of the invention;

FIGS. 3A, 3B, 4A and 4B are diagrams for describing how a fingerprint is collated;

FIGS. 5 to 8 are diagrams for describing the preprocessing (17) of the preferred embodiments of the invention; and

FIG. 9 illustrates a second preferred embodiment of the invention.

In the figures, the same reference numerals denote respectively the same constituent elements.

First will be described how the above-mentioned first disadvantage can be obviated.

In the aspect of the reduced rate of recognition, the problem with collation by the aforementioned processing apparatus inferior in computing capability consists in the identification merely by the presence of minutiae and the number of ridges in each pair of minutiae. One of the features of the present invention to solve this problem lies in its use of the detected absence of minutiae or of relations in any pair of minutiae for the collating purpose.

In a registered fingerprint image shown in FIG. 3A, black circles represent registered characteristic minutiae 21 used for collation.

It is supposed that a fingerprint image as shown in FIG. 3B, for instance, has been entered. This input fingerprint image has all the characteristic minutiae 21 in the fingerprint image of FIG. 3A, i.e. registered characteristic minutiae 22 shown in FIG. 3B, and non-registered characteristic minutiae 23, represented by white circles and not shown in the fingerprint image of FIG. 3A. Therefore, the fingerprint image of FIG. 3A and that of FIG. 3B are not identical. By the conventional collating method, however, only the registered characteristic minutiae 21 of FIG. 3A are searched. Therefore, the two fingerprints are treated as being identical because the registered characteristic minutiae 21 of FIG. 3A exist in FIG. 3B as minutiae 22.

A feature of the present invention consists in its use of information on non-characteristic minutiae besides that on characteristic minutiae.

In a fingerprint image equal to that shown in FIG. 3A, for instance, minutiae represented by black squares in FIG. 4A are supposed to be non-characteristic minutiae 32. In a collating operation, the positions of given non-characteristic minutiae are searched together with their vicinities in view of possible deviations, and the absence of characteristic minutiae is confirmed in those characteristic minutiae search areas 33. Therefore, if a fingerprint pattern equal to that shown in FIG. 3B is given, areas corresponding to the characteristic minutiae search areas 33 will be searched, resulting in the discovery of characteristic minutiae 35, which are absent in the fingerprint image of FIG. 4A, in a non-characteristic minutia surrounding area 37 represented by a broken-line square having a white square within in FIG. 4B.

Next will be described in detail a preferred embodiment of the present invention with reference to drawings.

First to illustrate the collating procedure characterizing the invention, an example of personal fingerprint data generation phase will be described.

Referring to FIG. 1, this example of personal fingerprint data generation phase consists of a registered fingerprint image inputting step 21; preprocessing 17 further comprising steps of image pick-up 2, direction extracting 3, direction smoothing 4 and ridge emphasizing 5; and registration processing 20 further comprising steps of aligning information generating 22, characteristic minutia detecting 23, non-characteristic minutia detecting 24, relation detecting 25 and collation minutia record preparing/registering 26. The collating points in this context include non-characteristic minutia besides characteristic minutia comprising end points and bifurcations.

This example of fingerprint data generating phase begins with the step 21 to input a fingerprint image to be registered. At this step 21, the fingerprint image can be taken either by dipping the fingertip in ink and sampling its image or by a "total reflection method" which utilizes the total reflection phenomenon arising on the boundary between a prism surface and the fingerprint ridges of the finger placed on that prism surface to obtain a fingerprint image at a high S/N ratio. Then, at the image pick-up step 2, the fingerprint image is optically read, converted into electric signals and stored into a memory as image data. The directions of ridges are extracted as follows from the image data thereby picked up at the direction extracting step 3. After that, the absolute values of the differences between the gray scale values of sets of every three pixels, arranged on radial lines

emanating in eight directions from a central (8, 8) pixel in each local area of 16 x 16 pixels shown in FIG. 5, and the gray scale value of the central pixel are summed. The direction of the least absolute values of the stated difference is supposed to be the directions of stream lines in local areas.

Then at the direction smoothing step 4, the directions of ridges are so adjusted as to be continuous into each adjoining block.

Then at the ridge emphasizing step 5, ridges are filtered and emphasized on the basis of the directions of the extracted ridges. Thus, for every pixel in the direction-extracted and direction-smoothed local areas, a filter conforming to the ridge direction, as shown in FIG. 7, is weighted as illustrated in FIG. 8 to emphasize the gray scale contrast dependent on directionality.

At the aligning information generating step 22, 5 x 5 blocks are selected in which the directions of ridges markedly vary. Thus, in order to achieve reference position aligning between the registered fingerprint and the input fingerprint in collation processing 19 referred to in FIG. 1, 5 x 5 directional patterns are selected from 16 x 16 directional patterns on the registered fingerprint image.

Then at the characteristic minutia detecting step 23, the positions and directions of characteristic minutiae are detected. Thus, the positions of end points and bifurcations on a binary image are detected by scanning block by block the binary image, resulting from the binarization of a gray scale image out of 256 x 256 pixels stored in an image memory. The directions thereby detected are identical with those determined at the direction smoothing step 4 for the respective blocks to which the detected characteristic minutiae belong. A collation minutia number is assigned to each detected characteristic minutia.

Next at the non-characteristic minutia detecting step 24, non-characteristic minutiae are detected in the following manner. A non-characteristic minutia is defined as the center of an area of a prescribed size in which no characteristic minutia is present. To detect a non-characteristic minutia, the central point of an area having no characteristic minutia is searched for by the same operation as what was conducted at the characteristic minutia detecting step 23. Its direction is identical with that determined at the direction smoothing step 4 for the area to which the detected non-characteristic minutia belongs. A collation minutia number is assigned to each detected non-characteristic minutia, too.

At the relation detecting step 25, four quadrants are determined, with one of the collation minutiae detected for a collation minutia number i being selected as the original. Out of the characteristic minutiae detected in each quadrant, the closest one to the original is selected. In the ab-

sence of a characteristic minutia in a quadrant, the closest non-characteristic minutia to the characteristic minutia of the original is determined. The characteristic minutia or non-characteristic minutia of each quadrant determined in this manner is called a neighboring collation minutia, referred to by the neighboring collation minutia number which is the applicable collation minutia number i.

If the collation minutia of the original and its neighboring collation minutia are characteristic minutiae, the number of ridges linking the two minutiae will be the relation value. In any other case, the value is "0".

After this processing, a collation minutia record list 27 shown in FIG. 2 is formed at the collation minutia record preparing/registering step 26. This list 27 has an average of 40 records for each fingerprint.

In the collating phase of the embodiment of the present invention, as its purpose is to identify individuals, personal fingerprint data consisting of the collation minutia record list 27, registered in the above described personal fingerprint data generating phase and, aligning data 28, are collated on a one-to-one basis with the input fingerprint entered by the registrant at the time of collation. Therefore, the embodiment of the invention uses a "top-down collating system", by which the registrant enters his or her ID number or a reasonable substitute therefor at the time of collation. The personal fingerprint data 27 and 28 pertaining to the registered fingerprints are accessed, and the characteristics of the registered fingerprints covered by the data are read out, resulting in direct verification on the input fingerprint image.

An example of collating phase of the preferred embodiment of the invention comprises a fingerprint image inputting step 1; preprocessing 17 further comprising steps of image pick-up 2, direction extracting 3, direction smoothing 4 and ridge emphasizing 5; positional correction processing 18; and collation processing 19 further comprising steps of search collation minutia selecting 7, local area setting 8, search collation minutia searching 9, neighboring collation minutia selecting 10, neighboring collation minutia searching 11, relation searching 12, scoring 13, frequency judging 14, scoring 15, threshold judging 16 and collation result outputting 17.

Operations of the fingerprint image inputting step 1 and the preprocessing 17 are identical with the corresponding operations in the above described record registering phase.

At the center aligning step 6 of the positional correction processing 18, aligning can be achieved by shifting a 5 x 5 directional data pattern, obtained as the aligning data 28 generated at the aligning information generating step 22 of the registering

phase, on the directional data of the input fingerprint to find out the best fitting position.

The fingerprint image having gone through aligning in this manner is inputted to the collation processing 19.

At the search collation minutia selecting step 7, the contents of the collation minutia record list 27 are referred to select collation minutia records in succession.

It is now supposed that a collating minutia record I has been selected.

Then at the local area setting step 8 is set a position on the input fingerprint image corresponding to the position of collation (X, Y). It is checked whether the input fingerprint image set in this manner has a collation minutia corresponding to the collation minutia of the collation minutia record I.

At the neighboring collation minutia selecting step 10 is searched a collation minutia record having a collation minutia number j indicated by a neighboring collation minutia number in the collation minutia record I selected at the selecting step 7.

Then at the searching step 11 is checked if there is a collation minutia in the position of the input fingerprint image indicated by a collation minutia in the record j.

Next at the relation searching step 12, reference is made to a relation field in the record I to check if the number of ridges on the segment linking two corresponding points in the record I and the record j of the input fingerprint image is equal to the number of ridges stated in the field referred to.

At the scoring step 13, the degree of matching is weighted with the difference between the detected relation and the relation in the collation minutia record list 27. If, for instance, the difference is great, the score will be reduced or, if the difference is small, the score will be raised.

At the prescribed frequency judging step 14, the prescribed frequency is four times because four quadrants are searched. To achieve a higher level of accuracy, however, the prescribed frequency may be a power of four.

At the scoring step 15 are detected four approximate collation minutiae for a collation minutia which is the single original, and one collation minutia record is checked as to whether the collation minutia, which is made the original, is identical with the registered collation minutia in accordance with a predetermined value of the total sum of relation-based weights.

At the threshold judging step 16 is judged whether the number of collation minutia records judged at the scoring step 14 has reached a prescribed number.

As regards this number, the number of identical minutiae may be "20" for instance, or that of unidentical ones, say, "5".

In this way are achieved personal fingerprint data generation and collation for collation minutiae including non-characteristic minutiae.

In respect of the speed of image processing, search/collation processing of non-characteristic minutiae can be executed as fast as that of characteristic minutiae.

A second preferred embodiment of the present invention, in which is realized this example using a table of random numbers by separating the image processing side and the IC card from each other, will be described in detail below with reference to a drawing.

Referring to FIG. 9, in the second preferred embodiment of the invention, a collation demand is first generated in an image processing unit 31 (step 32). In response to this collation demand are read out aligning data 28, which constitute part of personal fingerprint data in the IC card 30. Along with that, in the image processing unit 31 are performed, like in the first preferred embodiment of the invention, fingerprint inputting 1, preprocessing 17 and positional correction processing 18. This positional correction processing 18 utilizes the aligning data 28 provided from the IC card 30.

This second embodiment will be described in detail below with respect to its second feature, the use of random numbers in characteristic minutia searching, besides the first feature, the use of the IC card 30.

First, a random number table 34 is accessed according to a few of the least significant bits in a timer 33 built into the IC card 30. Next, according to a random number read out of this random number table 34, a collation minutia list 27 is accessed to read out a collation minutia record. At a search collation minutia selecting step 7, the position (X, Y) and direction of the collation minutia are determined on the basis of the contents of the collation minutia record which has been read out, and supplied to the image processing unit 31. In the image processing unit 31, like in the first embodiment, are executed a local area setting step 8 and a search collation minutia searching step 9, and the type of the collation minutia, as the result of search, is sent to the IC card 30. In the IC card 30, the same record as what was referenced at the foregoing selecting step 7 is referenced on the basis of the result of search; the position and direction of a neighboring collation minutia are determined, and provided to the image processing unit. In the image processing unit 31, like in the first embodiment, are executed a neighboring collation minutia searching step 11 and a relation searching step 12 on the basis of the position and direction of the neighbor-

ing collation minutia, and the type of the collation minutia and the relation, as the result of search, are sent to the IC card 30. In this manner, collation can be executed without having to inform the image processing side of the type of the collation minutia and the relation in advance.

At a scoring step 13, a frequency judging step 14 and another scoring step 15 in the IC card 30, respectively the same processings are achieved as in the first preferred embodiment.

The image processing unit 31 in this second embodiment, as it cannot tell whether registered characteristic minutiae are present in the positions inquired about, can hardly infer the contents of the registered collation minutia list from the inquiry. However, even though inference from the inquiry is hardly possible, the combination of the inquiry and the result of collation using the reply thereto may readily allow the information to leak, depending on the method of collation. For instance, if only one minutia is inquired about and the result of collation as to its legitimacy alone is referenced, it will be known whether the response from the image processing unit 31 was as stated in the collation minutia record list. If the result of collation is considered affirmative only when all the replies to the inquiry are affirmative, a tapping third party will know the affirmative answer to every item of the inquiry. In respect of reliability, conversely, noise in the input image may invite a failure in identifying the right person. In view of this problem, at step 16 of the first preferred embodiment of the invention, a threshold is prescribed for the number of affirmative replies at or beyond which collation is deemed affirmative, and another threshold is provided for negative replies at or beyond which the person cannot be legitimately identified.

If, at the time the number of either positive or negative replies has reached its threshold, the fact of its having been reached is made known to the image processing unit 31, it will be known that the reply to the last question has brought the number of positive or negative replies to its threshold. Thus, if the person is identified, the final reply must have been positive or if not, it must have been negative. This leaves a problem in keeping the secrecy of the list of characteristic minutiae concerning the final question.

At a prescribed frequency step 20 in the second preferred embodiment of the present invention, the IC card 30 makes inquiries to, and receives replies from, the image processing unit 31 a prescribed number of times beyond the threshold about the positions and directions of collation minutiae and neighboring collation minutiae, and only then completes the collating process by informing the image processing unit 31 of the result of collation. However, if there is neither fear of tapping by

a third party nor the need to keep the list of collation minutiae secret from the legitimate person to be identified, it will be a waste of time and communication quantity to continue making inquiries until the prescribed number is reached even though the threshold number of positive replies has been arrived at. In this case, the IC card 30 will send the result of collation to the image processing unit 31 when the threshold number of positive replies has been reached or, if the number of negative answers exceeds its threshold, will let inquiries continue to be made until their prescribed number is reached.

The present invention has the advantage of improving the collation rate by using not only characteristic minutiae but also non-characteristic minutiae for the collation purpose. It has the further advantage that the image processing unit does not know whether the collation minutiae searched for are characteristic or non-characteristic and therefore cannot recognize genuine characteristic minutiae, neighboring characteristic minutiae or relations among them, because the IC card has the list of collation minutia records. It has the still further advantage of being able to keep the secrecy of the contents of the collation minutia record list more effectively by utilizing random numbers for accessing the collation minutia record list in the IC card, using a different collation minutia record list every time, and setting the frequency of placing inquiries with the image processing unit about collation minutia information at any convenient number greater than the threshold.

Claims

1. A method for the matching of fingerprints comprising an inputting step to enter a fingerprint image, and
40 a collating step to check the collation minutiae of the input fingerprint image, consisting of both characteristic minutiae, that is branching parts (bifurcations) and abrupt endings (end points) of ridges and non-characteristic minutiae that is fingerprint areas without any characteristic minutiae, with the collation minutiae already registered in a list of collation minutia records.
2. An apparatus for the matching of fingerprints comprising an IC card having minutia record holding means for holding collation minutiae consisting of both characteristic minutiae, that is branching parts (bifurcations) and abrupt endings (end points) of ridges and non-characteristic minutiae that is fingerprint areas without any characteristic minutiae, and
55 sending means for sending collation minu-

tia information from the minutia record holding means to an image processing unit; and
 the image processing unit having collation minutia searching means responsive to the collation minutia information from the sending means of the IC card for searching the collation minutiae and sending the result of search to said IC card.

3. An apparatus for the matching of fingerprints, as claimed in Claim 2, wherein said minutia record holding means in said IC card is accessed by random numbers.

4. An apparatus for the matching of fingerprints, as claimed in Claim 2 or 3 wherein said IC card sets the permissible frequency of sending by said sending means in response to the result of search from the collation minutia searching means of said image processing unit at any desired value greater than a predetermined level.

Patentansprüche

1. Verfahren zum Vergleichen von Fingerabdrücken mit einer Eingabestufe zur Eingabe eines Fingerabdruckbilds sowie einer Abgleichstufe zur Prüfung der Abgleichminutien des eingegebenen Fingerabdruckbilds, das sowohl aus charakteristischen Minutien, d. h. Gabelungen (Bifurkationen) und abrupte Abschlüsse (Endpunkte) von Papillarlinien, als auch aus nicht charakteristischen Minutien, d. h. Fingerabdruckbereiche ohne charakteristische Minutien, besteht, wobei die Abgleichminutien bereits in einer Liste von Abgleichminutiensätzen registriert sind.

2. Vorrichtung zum Vergleichen von Fingerabdrücken mit einer IC-Karte mit Speichermitteln für Minutiensätze zum Speichern von Abgleichminutien, die sowohl aus charakteristischen, d. h. Gabelungen (Bifurkationen) und abrupte Abschlüsse (Endpunkte) von Papillarlinien, als auch aus nicht charakteristischen Minutien, d. h. Fingerabdruckbereiche ohne charakteristische Minutien, bestehen, sowie Sendemittel zum Senden von Angaben über Abgleichminutien aus den Speichermitteln für Minutiensätze zu einer Bildverarbeitungseinheit, wobei die Bildverarbeitungseinheit Suchmittel für Abgleichminutien hat, die als Reaktion auf die Angaben über Abgleichminutien von den Sendemitteln der IC-Karte die Abgleichminutien suchen und das Suchergebnis zur IC-Karte senden.

3. Vorrichtung zum Vergleichen von Fingerabdrücken nach Anspruch 2, wobei auf die Speichermittel für Minutiensätze in der IC-Karte über Zufallszahlen zugegriffen wird.

4. Vorrichtung zum Vergleichen von Fingerabdrücken nach Anspruch 2 oder 3, wobei die IC-Karte die zulässige Sendehäufigkeit der Sendemittel als Reaktion auf das Suchergebnis von den Suchmitteln für Abgleichminutien der Bildverarbeitungseinheit auf jeden gewünschten, eine vorbestimmte Größe übersteigenden Wert einstellt.

Revendications

1. Procédé pour la comparaison d'empreintes digitales comprenant une étape de lecture pour lire une image d'empreintes digitales, et une étape d'interclassement pour comparer les détails d'interclassement de l'image d'empreintes digitales lue, ceux-ci comprenant à la fois des détails caractéristiques, c'est-à-dire des parties ramifiées (bifurcations) et des extrémités abruptes (points d'extrémité) des sillons, et des détails non caractéristiques, c'est-à-dire des zones des empreintes digitales sans détails caractéristiques, avec les détails interclassés déjà enregistrés dans une liste d'enregistrements de détails d'interclassement.

2. Dispositif pour la comparaison d'empreintes digitales comprenant une carte à CI ayant un moyen de stockage d'enregistrements de détails pour stocker des détails d'interclassement comprenant à la fois des détails caractéristiques, c'est-à-dire des parties ramifiées (bifurcations) et des extrémités abruptes (points d'extrémité) des sillons, et des détails non caractéristiques, c'est-à-dire des zones des empreintes digitales sans détails caractéristiques, et un moyen d'envoi pour envoyer les informations de détails du moyen de stockage d'enregistrements de détails, à une unité de traitement d'images; et
 l'unité de traitement d'images ayant un moyen de recherche des détails d'interclassement répondant aux informations de détails d'interclassement provenant du moyen d'envoi venant de la carte à CI en recherchant les détails d'interclassement et en envoyant le résultat de la recherche à ladite carte à CI.

3. Dispositif pour la comparaison d'empreintes digitales selon la revendication 2, dans lequel ledit moyen de stockage d'enregistrements de détails dans ladite carte à CI, fait l'objet d'accès à l'aide de nombres aléatoires.

4. Dispositif pour la comparaison d'empreintes digitales selon la revendication 2 ou 3, dans lequel ladite carte à CI fixe la fréquence admissible d'envoi par ledit moyen d'envoi en réponse au résultat de la recherche effectuée par le moyen de recherche de détails d'inter-classement de ladite unité de traitement d'images, à une valeur souhaitée quelconque supérieure à un niveau prédéterminé.

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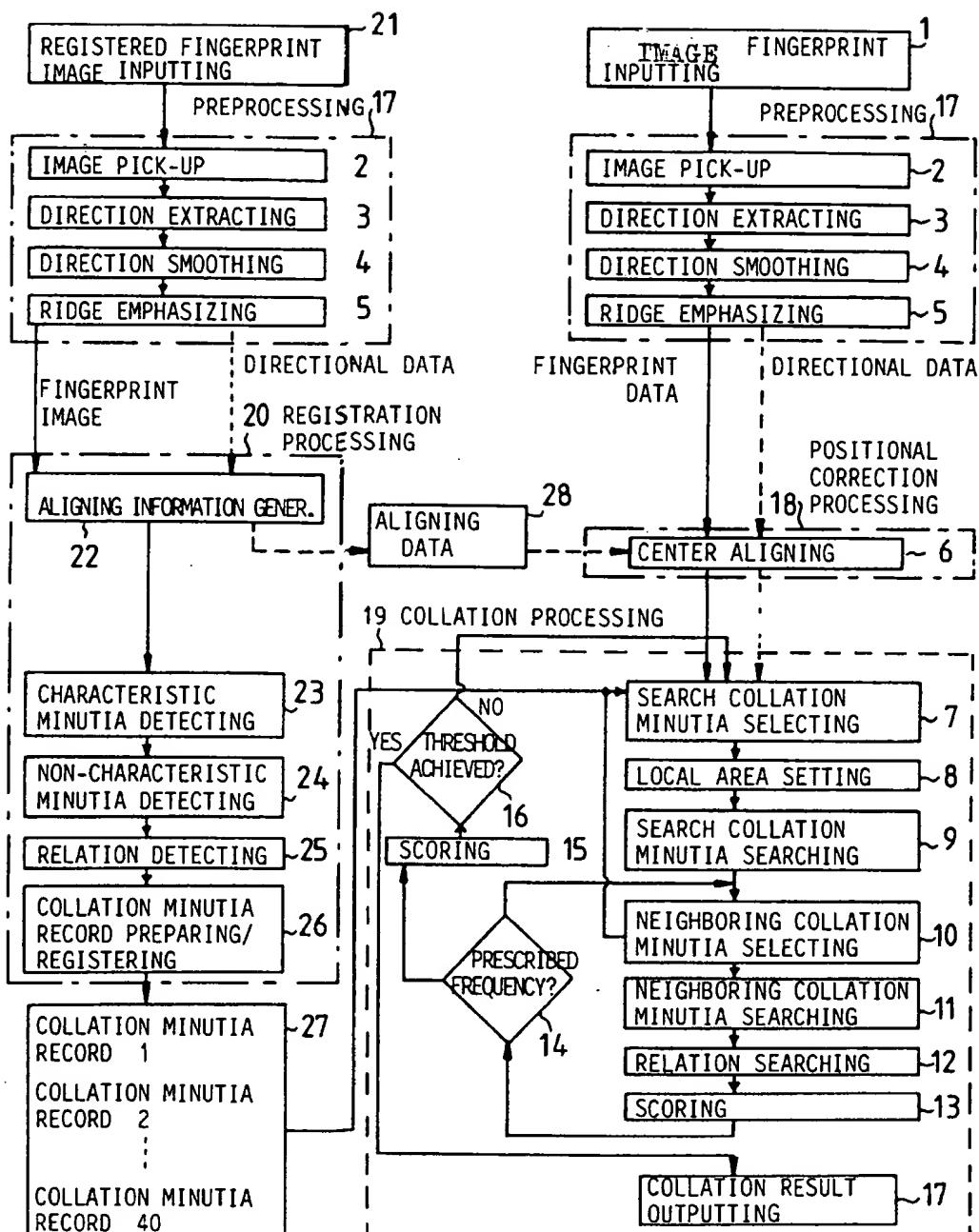
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Fig. 1



PERSONAL FINGERPRINT DATA

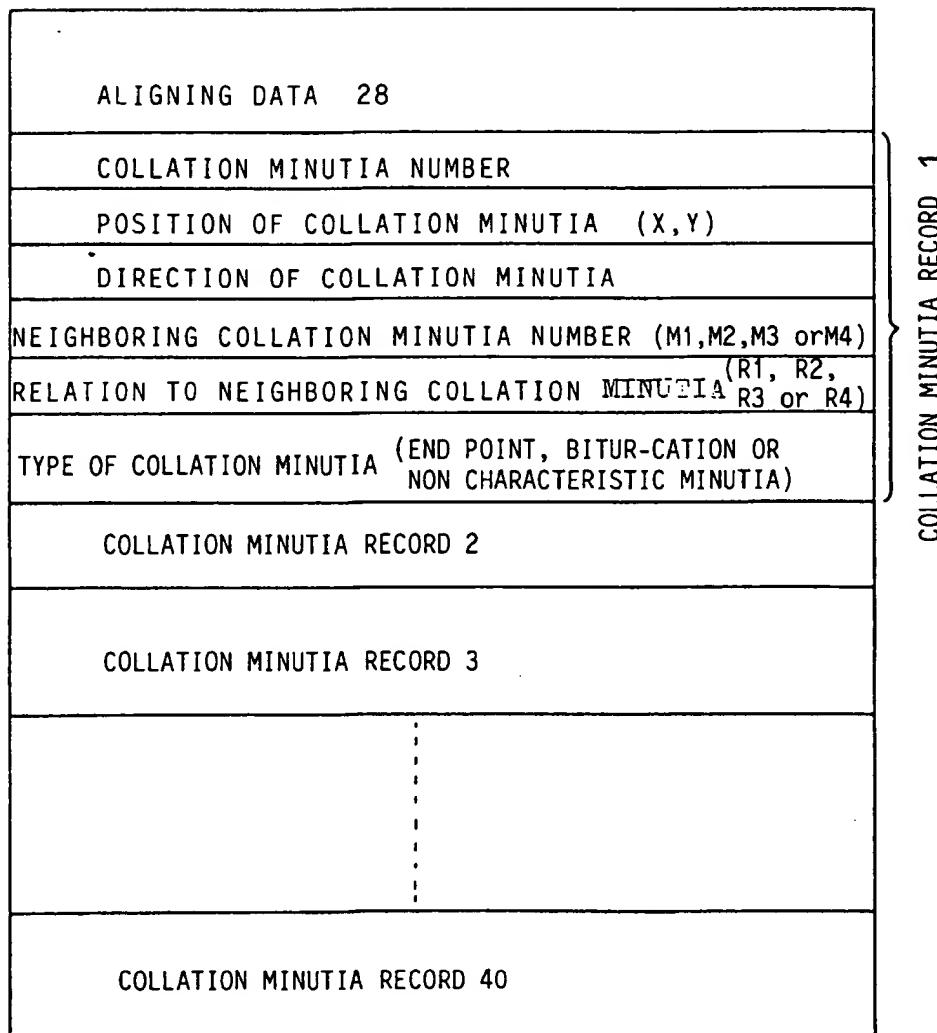
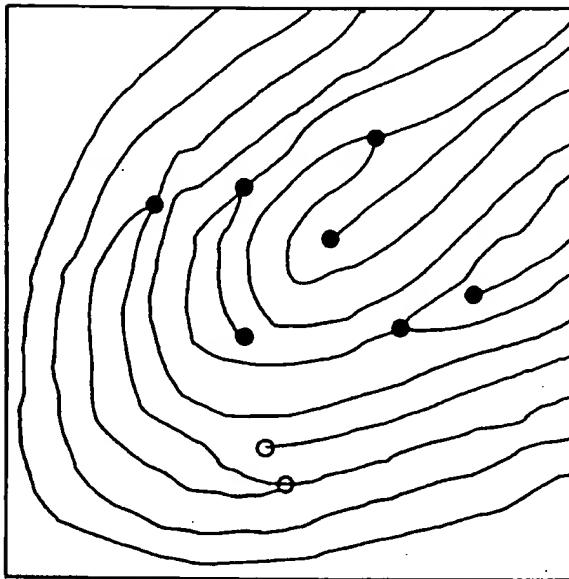
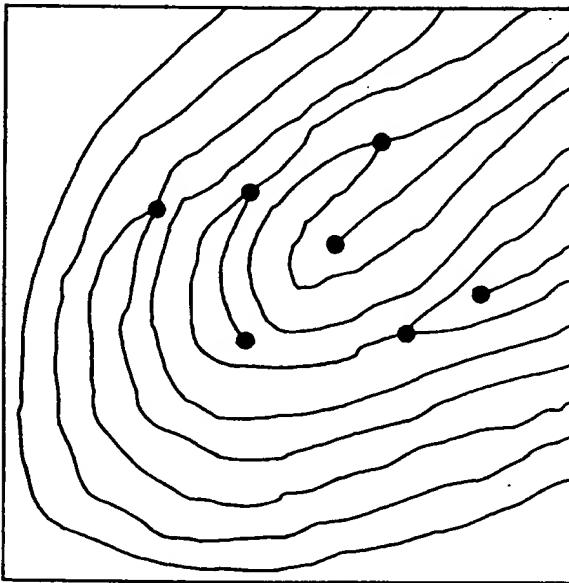


Fig. 2

Fig. 3

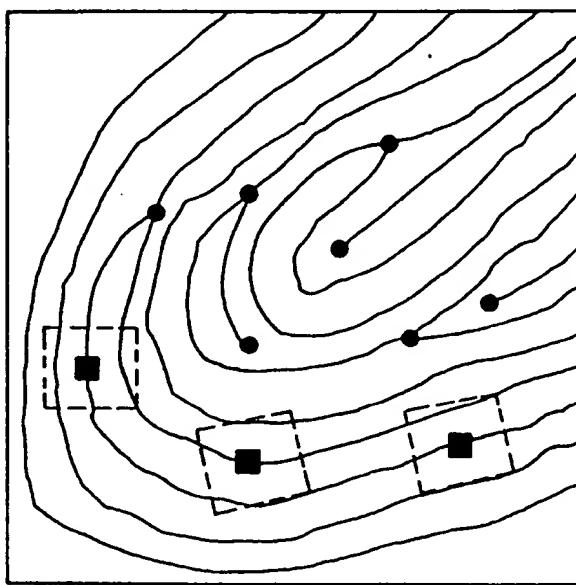
B



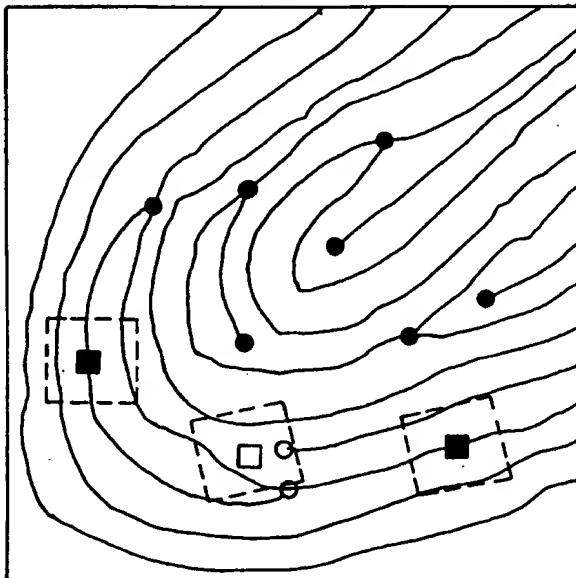
- REGISTERED CHARACTERISTIC
MINUTIA 21
- OTHER CHARACTERISTIC MINUTIA
THAN REGISTERED CHARACTERISTIC
MINUTIA 23

Fig. 4

B



- REGISTERED CHARACTERISTIC
 - MINUTIA 31
 - NON-CHARACTERISTIC MINUTIA 32
- CHARACTERISTIC MINUTIA
SEARCH AREA 33



- CHARACTERISTIC MINUTIA PRESENT IN BOTH FIGS. 4A and 4B 34
- CHARACTERISTIC MINUTIA PRESENT ONLY IN FIG. 4B 35
 - NON-CHARACTERISTIC MINUTIA AREA IN BOTH FIGS. 3A AND 3B 36
 - NON-CHARACTERISTIC MINUTIA ONLY IN FIG. 4A 37

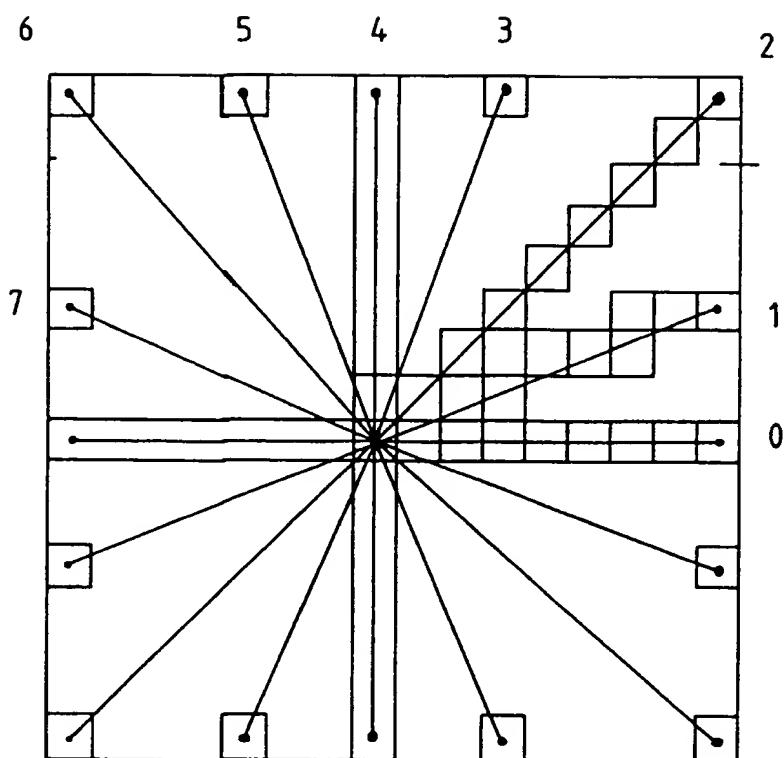


Fig. 5

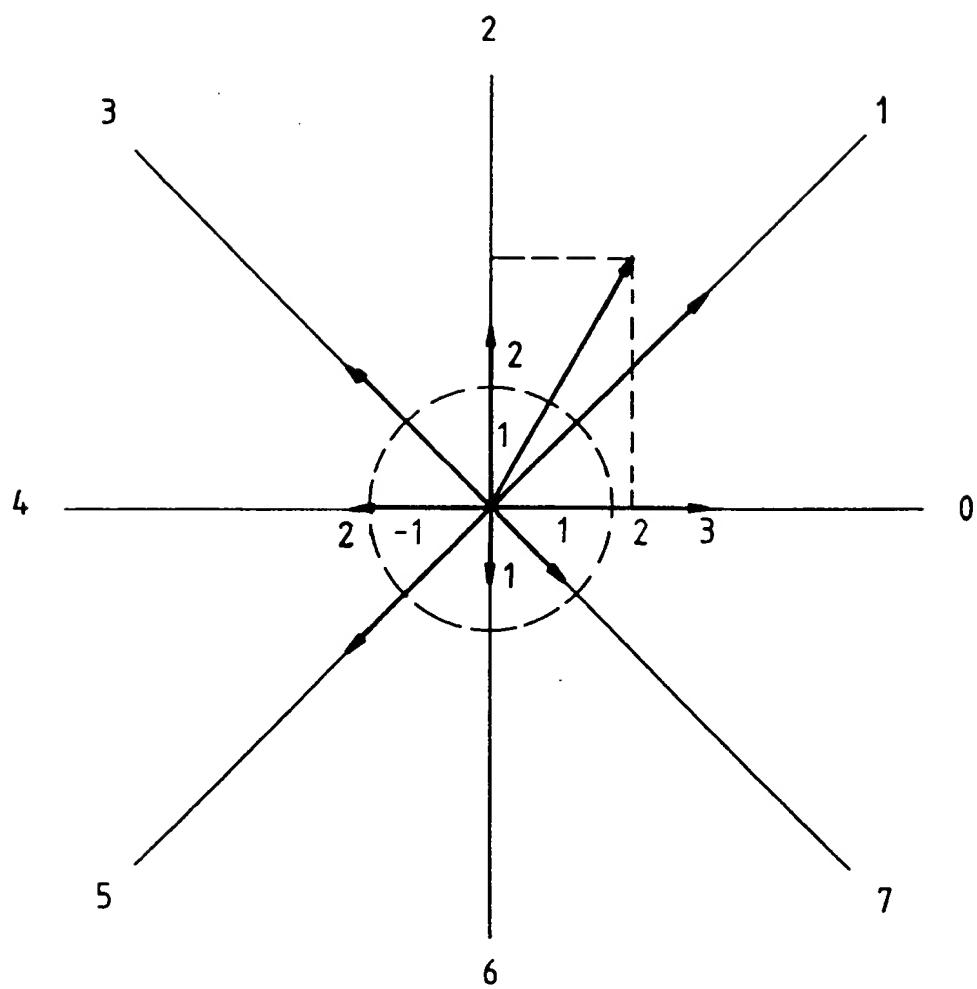
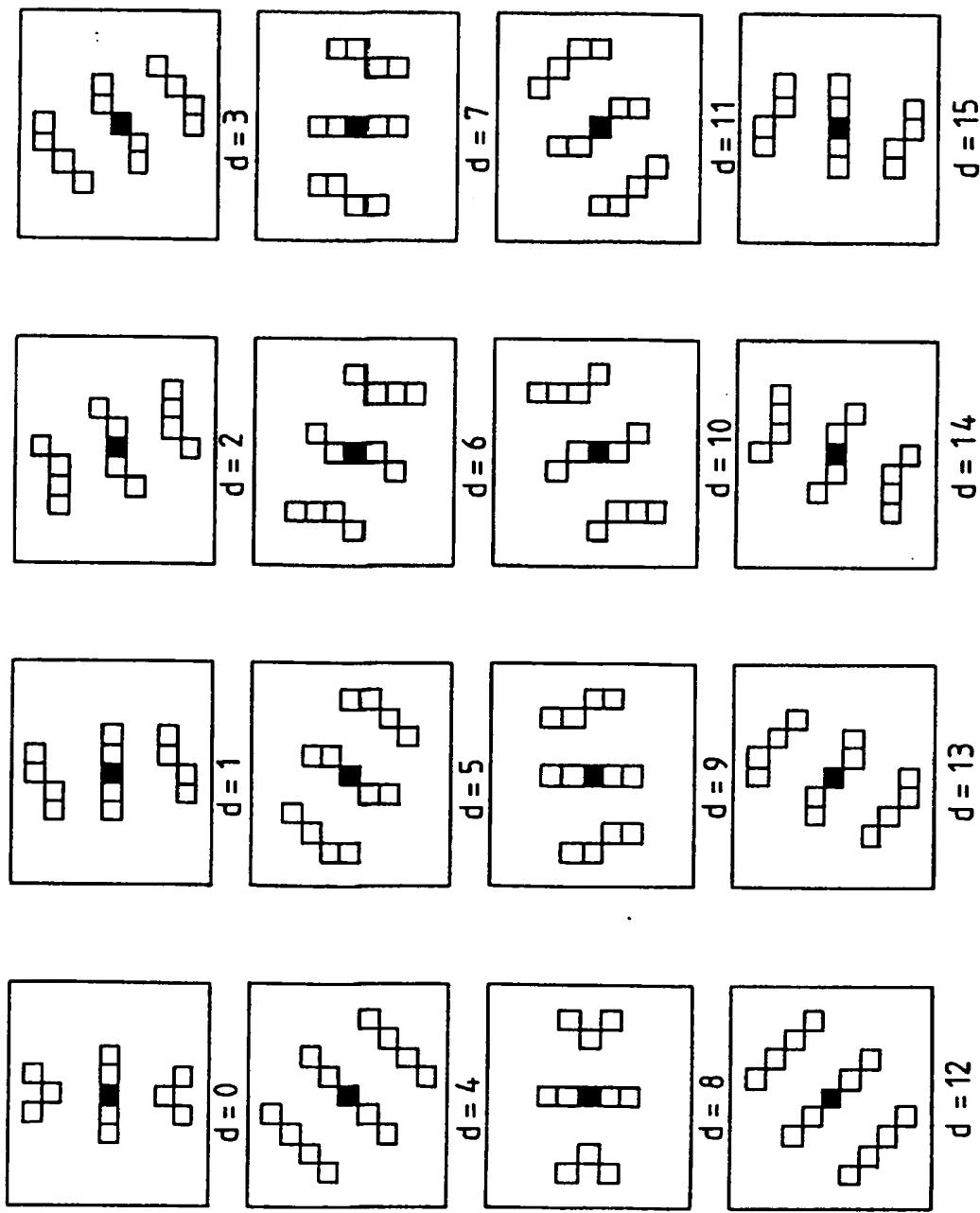
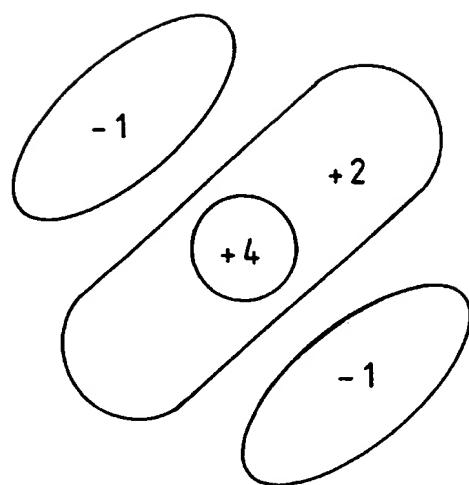


Fig. 6

Fig. 7





CASE OF $d = 4$

Fig. 8

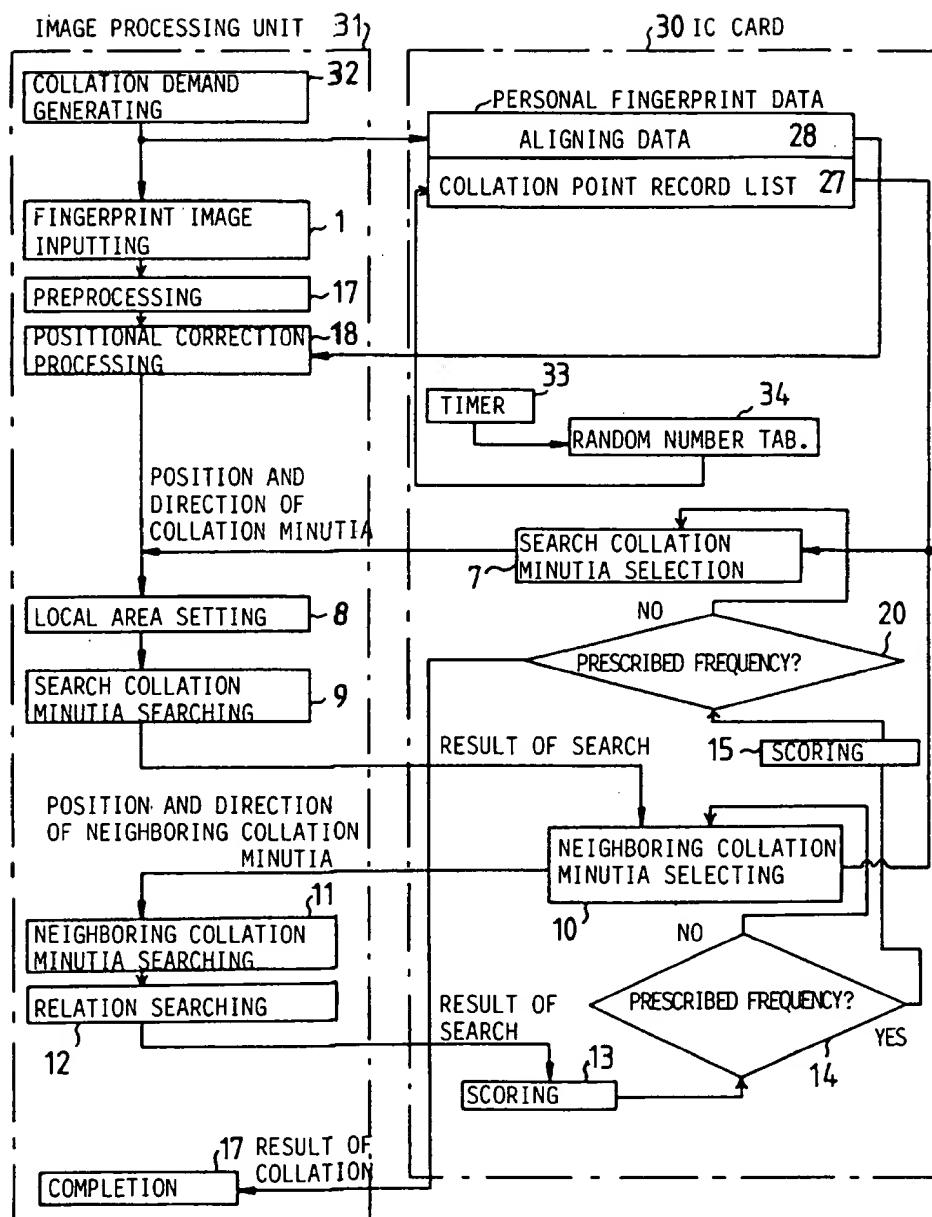


Fig. 9